

Performance of the LHCb RICH detectors during the LHC Run II

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Abstract

The LHCb RICH system provides hadron identification over a wide momentum range (2–100 GeV/ c). This detector system is key to LHCb's precision flavour physics programme, which has unique sensitivity to physics beyond the standard model. This paper reports on the performance of the LHCb RICH in Run II, following significant changes in the detector and operating conditions. The changes include the refurbishment of significant number of photon detectors, assembled using new vacuum technologies, and the removal of the aerogel radiator. The start of Run II of the LHC saw the beam energy increase to 6.5 TeV per beam and a new trigger strategy for LHCb with full online detector calibration. The RICH information has also been made available for all trigger streams in the High Level Trigger for the first time.

1 Introduction

After the start of Run II in 2015 at the LHC [1] the LHCb experiment [2] has been able to study the properties and decays of mesons containing b and c quarks produced at a pp centre-of-mass energy of 13 TeV. The crucial task of hadron identification is performed by a Ring Imaging Cherenkov (RICH) system using two RICH detectors with gas radiators [3,4]. For Run II LHCb has been able to collect data with a much higher efficiency thanks to a new trigger strategy. The Level 0 hardware trigger remains the same as in Run I (2009–2013), however, the High Level software Trigger (HLT) has been split into two parts. HLT1 is a fast track-based trigger that runs online with an output rate of ~ 100 kHz. The data are buffered on local disks, and then read by the HLT2, after the sub-detector systems have been calibrated and aligned (see Figure 1). This results in almost offline-quality datasets straight from the LHCb trigger. For this strategy to work it is required that the same algorithms are used online and offline. This increases the need for speed optimisation in the event reconstruction. These changes had a big impact on all subsystems, including the RICH [5]. With the new trigger strategy the RICH particle identification (ID) information is used in HLT2 for all trigger streams. Some physics analyses take advantage of this and can be done without the extra step of offline reprocessing of the events.

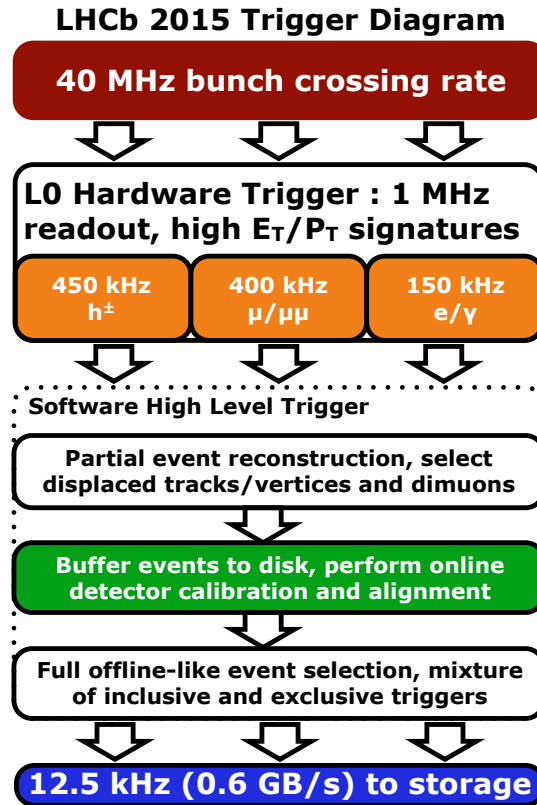


Figure 1: The LHCb Run II trigger scheme illustrating the importance of the detector alignment and calibration before the HLT2 step.

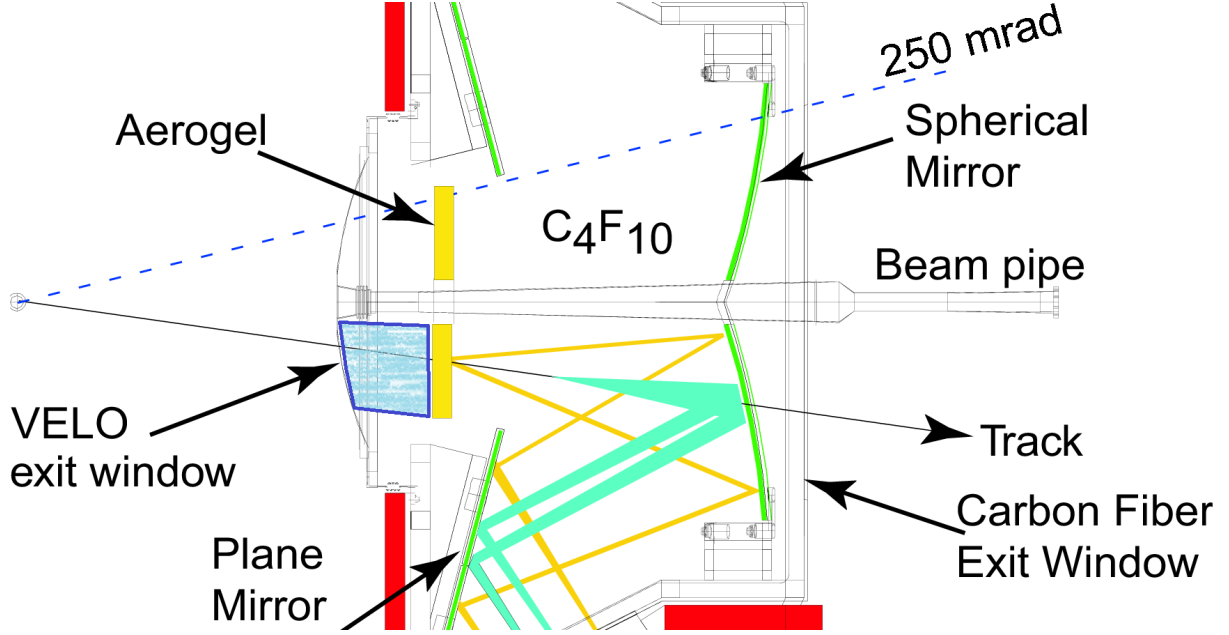


Figure 2: A section of the RICH 1 schematic showing the gas volume from the side. While the aerogel radiator was in place the Cherenkov photons generated in the shaded blue area filled with C_4F_{10} would be blocked. With the removal of the box these photons are free to reach the photon detectors.

2 Changes in the RICH System for Run II

The LHCb RICH system consists of two RICH detectors: RICH 1 located upstream of the LHCb magnet and close to the interaction point and RICH 2 located downstream of the tracking system and before the calorimeter. Both detectors have gas radiators (C_4F_{10} and CF_4 respectively) while RICH 1 also used aerogel in Run I. The RICH detectors were re-optimised following Run I taking into account the new requirements for the event reconstruction and the need to run the same algorithms online and offline. The aerogel radiator was removed as its ability to provide particle ID for particles below the C_4F_{10} Cherenkov threshold for kaons is compromised by the total number of photons in RICH 1 in such a high track multiplicity environment. At the same time its removal allowed the full use of the gas radiator that is located between the RICH 1 entrance window and the aerogel (Figure 2, shaded blue area). Removing it also contributed significantly to the speed of the RICH reconstruction as it reduced by more than half the number of photon candidates (combinations of photon-detector hits with tracks) for which a Cherenkov angle is calculated.

The operation of the LHCb RICH Hybrid Photon Detectors (HPDs) and the observed vacuum degradation on a small number of them has been documented in the past [6]. With no need for HPD refurbishment between Run I and II, the manufacturer improved the refurbishing process resulting in HPDs with extremely low ion feedback (i.e. very good vacuum quality) and no sign of vacuum degradation.

There are also small improvements in the composition of the gas radiators. In RICH 1 a liquefying stage was added in the gas re-circulation that allows the purification of the C_4F_{10} gas (mainly the removal of nitrogen) when needed. In RICH 2 the average amount

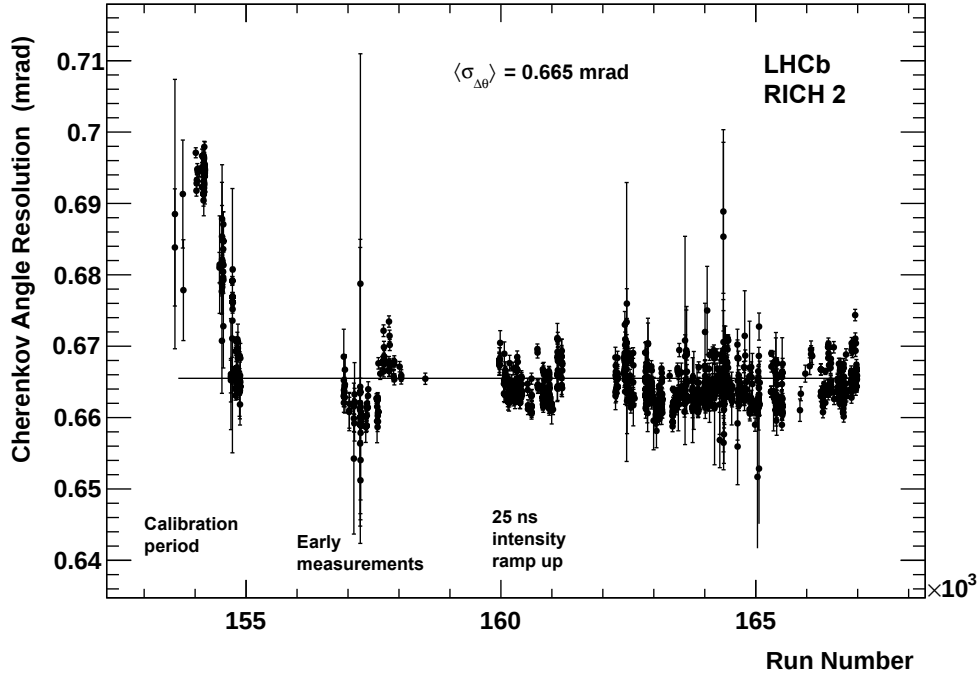


Figure 3: RICH2 single photon resolution for the summer and early autumn of 2015. Every point represents the resolution in one run with a maximum duration of one hour. The horizontal line is the average of all the runs after 155000.

of CO_2 was increased to about 10% in order to reduce the CF_4 scintillation.

2.1 Cherenkov angle resolution

The changes mentioned above were not expected to affect the Cherenkov angle resolution. Indeed the single photon resolution has remained unchanged between Run I and Run II. The average value for RICH 1 is 1.65 mrad and for RICH 2 0.67 mrad. Figure 3 shows a plot with a resolution value for every physics run in the summer and early autumn of 2015 for RICH2. The maximum duration for a run is one hour. After the initial alignment of the mirrors (runs before 155000), the resolution is very stable, giving consistent performance throughout the year.

3 RICH Particle ID Calibration

The performance of the RICH system in particle identification is obtained from data. It is possible to obtain pure particle samples of known species (pions, kaons and protons) from decays with well defined topologies (seen in Table 1) without using the RICH [7] system. Comparison of the known particles from the calibration samples with the RICH identification quantifies how well the RICH system performs. Care must be taken to ensure that the calibration samples share similar ranges in momentum and angular distributions with the physics analysis samples. In Run II there has been an increase in the range of

Table 1: Decays with well defined topology which can be efficiently identified without RICH information

Species	Low p and p_t	High p and p_t
$\pi^\pm$	$K_s^0 \rightarrow \pi^+\pi^-$	$D^* \rightarrow D^0(K^-\pi^+)\pi^+$
$K^\pm$	$D_s^+ \rightarrow K^+K^-\pi^+$	$D^* \rightarrow D^0(K^-\pi^+)\pi^+$
$p^\pm$	$\Lambda^0 \rightarrow p\pi^-$	$\Lambda^0 \rightarrow p\pi^-, \Lambda_c^+ \rightarrow pK^-\pi^+$

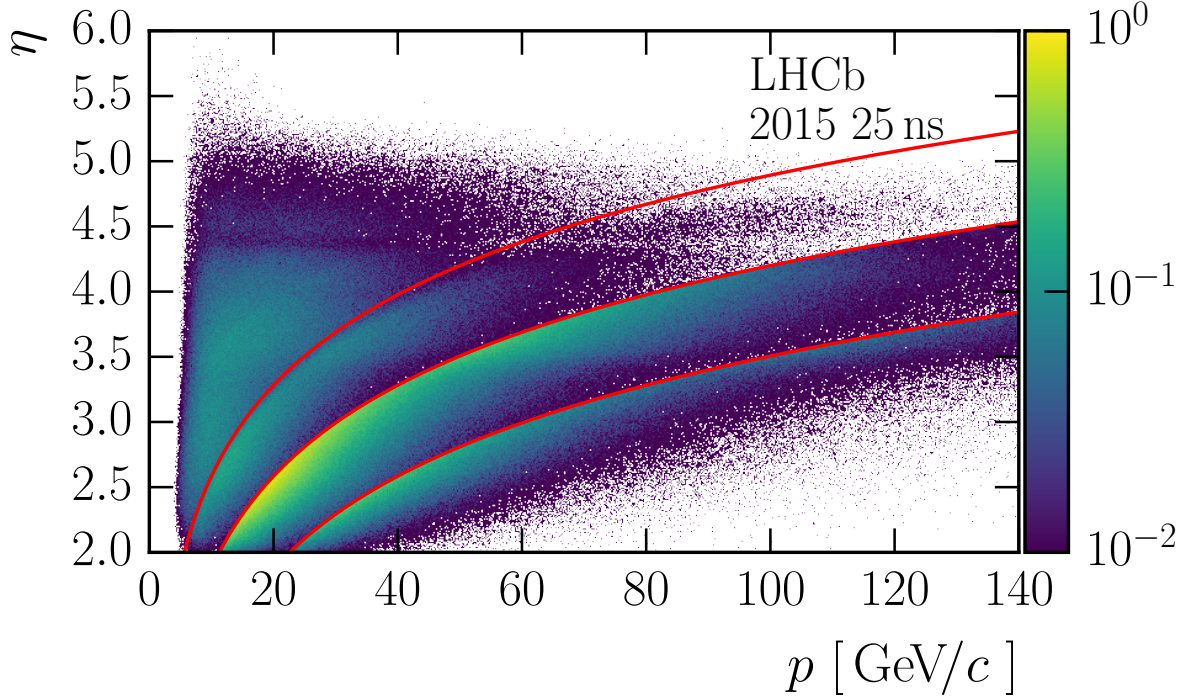


Figure 4: The kinematic range in momentum p and pseudorapidity η of the calibration samples for protons. The red lines correspond to p_T thresholds of 1.5, 3.0 and 6.0 GeV/ c . The units on the colour bar scale are arbitrary.

momentum and pseudorapidity of the calibration samples to better match the physics events of interest (Figure 4 for protons).

4 Particle Identification Performance

Using particle samples of known species, as described above (section 3), it is possible to estimate the performance of the RICH system in terms of particle ID. The efficiency of the system can be traded against purity. Figure 5 (top) shows the efficiency and mis-identification of kaons versus momentum for the 2015 data taking period. Efficiency and mis-identification are shown for two different values of the decision-making variable (the difference in the likelihood). For a particular physics study the performance can be tuned to match the requirements of the analysis. The same data are shown at the bottom part of the figure for the 2012 data taking period (during Run I). The performance looks generally similar apart from the mis-identification curves at low momentum. It is clear that in 2015, after all the changes described in section 2, the performance is better. The

purity has improved without any sacrifice in efficiency.

Although Figure 5 shows that the overall performance of the RICH system has improved in Run II, comparison with 2012 is not straightforward as the beam energy and data taking conditions are not the same. While studying the performance in 2015 it became clear that changing the trigger conditions and altering the mix of selected events had an impact on the measured RICH performance. It is however also important to understand the intrinsic performance of the LHCb RICH system. The parameters that most affect the performance of the RICH, apart from the particle momentum, are the complexity of the event (the number of tracks) and the pseudorapidity of the track. The Run I data is re-weighted to correct for differences in the distribution of the number of tracks per event compared to Run II data. After this step the performance is studied in bins of η and momentum. Figure 6 shows the comparison of the performance between 2012 (dash lines) and 2015 (solid lines). Each small plot shows the mis-identification versus the efficiency for a range of momentum and η for 2012 and 2015 data. The top plot shows the performance in pion-kaon separation and the lower plot the same for kaons and protons. The plots are produced by varying the difference in likelihood between the two particles under test. Looking at the performance of the RICH system in this way provides detailed and useful information. It is worth noting that the kaon threshold in RICH1 is $9.4 \text{ GeV}/c$ and that RICH2 covers angles $\eta \gtrsim 2.5$. In the comparison of the 2012-2015 performance it is clear that certain regions of phase space have improved while in others the performance has not changed. In the entire $\eta - p$ phase-space there is no performance degradation. Any degradation in performance due to the removal of the aerogel would be seen at lower particle momenta, and particularly for K -proton separation. This is not seen, indicating that the benefit from the higher Cherenkov photon yield more than compensates for the loss of information from the aerogel. It should be pointed out that the RICH particle ID is always used together with tracking and other subsystem information in the event and the binary differentiation between two particle species represents the way it is actually used in physics studies.

5 Conclusions

Extensive work took place following Run I in 2013-14 to prepare the LHCb RICH detectors for LHCb Run II. The biggest change for the LHCb Run II was the removal of the aerogel radiator. A large number of photon detectors was exchanged with refurbished ones having significantly better vacuum quality and the readout electronics were better tuned for the LHCb data taking conditions. The re-circulation of the gas radiators was also improved.

All of these changes have had a positive impact in the particle identification performance. The separation between pions and kaons has been improved, especially in the momentum region of $2\text{--}20 \text{ GeV}/c$. Detailed studies and comparison between the 2012 and 2015 show that this improvement is intrinsic to the RICH system and not the result of any change in the data taking conditions.

References

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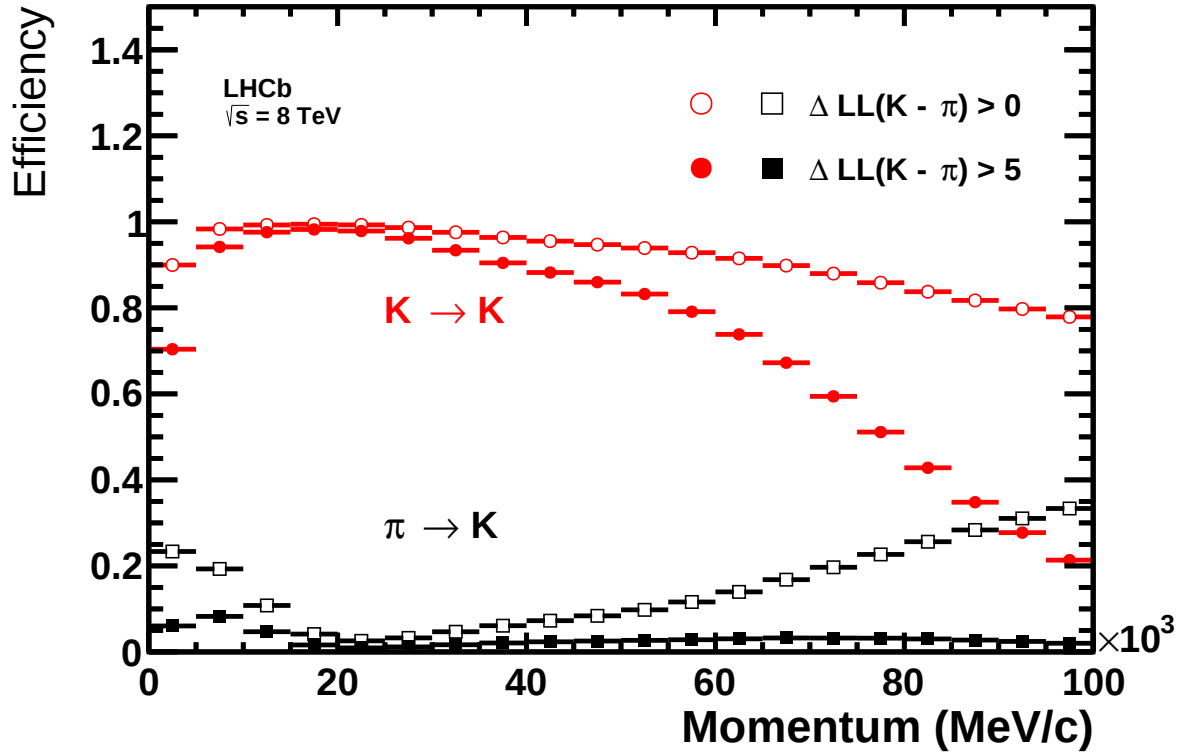
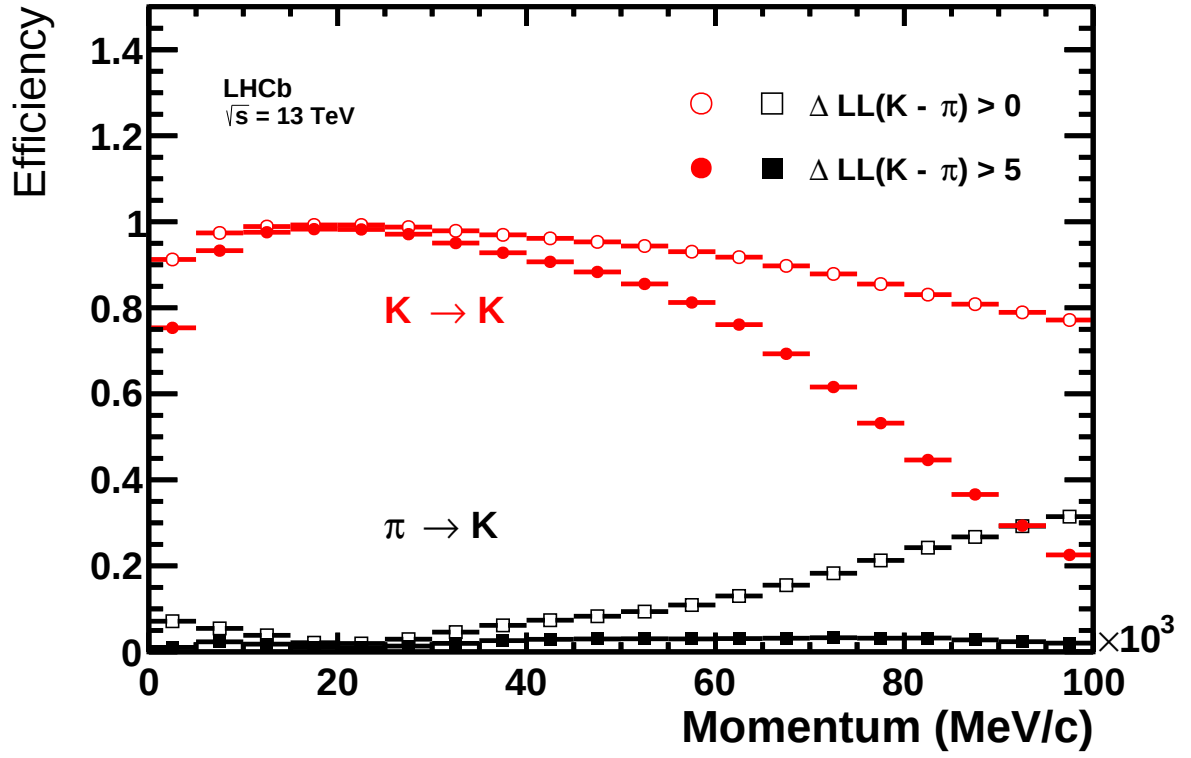
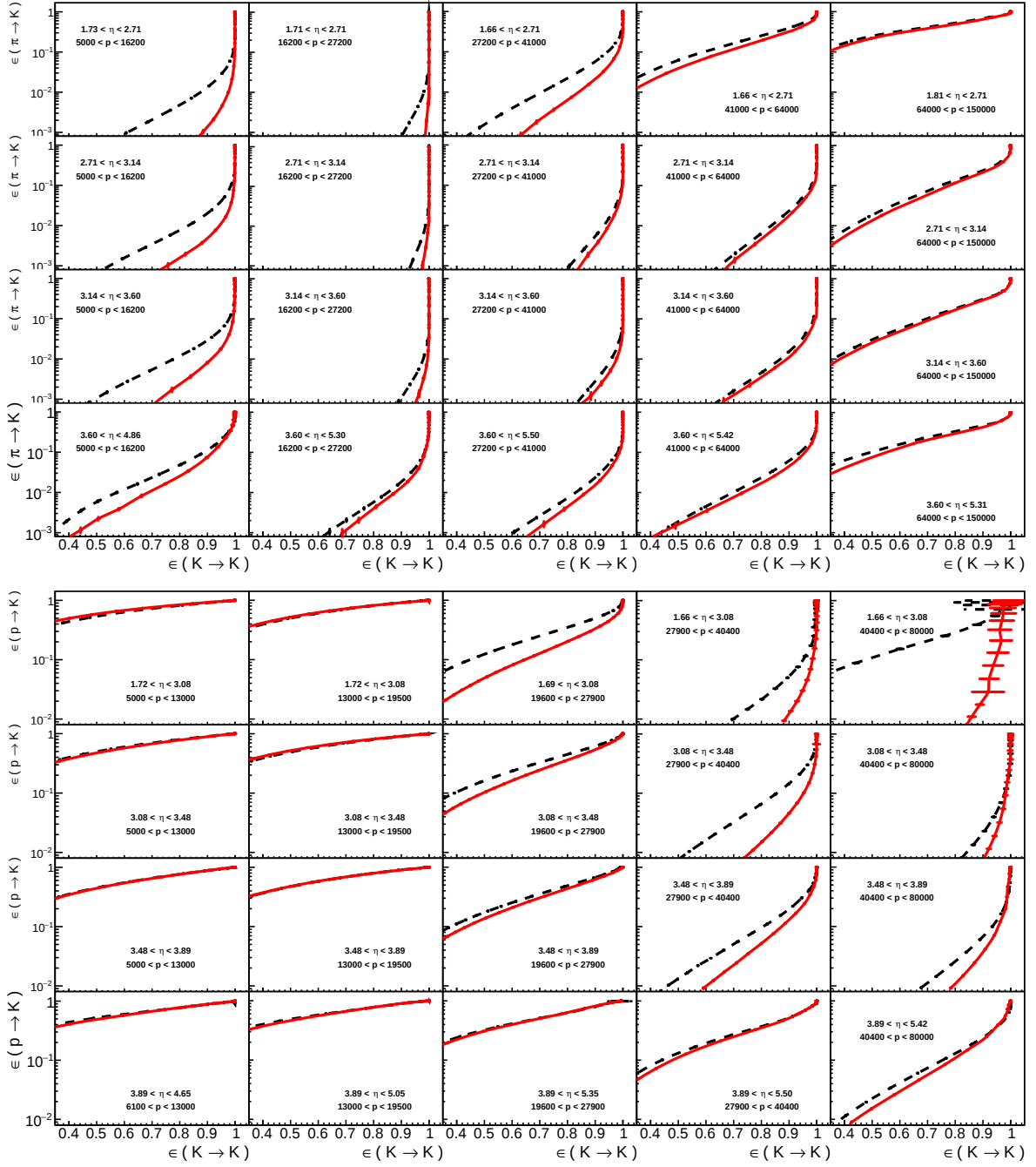


Figure 5: Kaon ID performance (efficiency ($K \rightarrow K$ and mis-ID of pions as Kaons ($\pi \rightarrow K$)) versus momentum for two different cuts in the likelihood difference (decision making variable). At the top the data correspond to 2015 and the bottom to the 2012 period of data taking.



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